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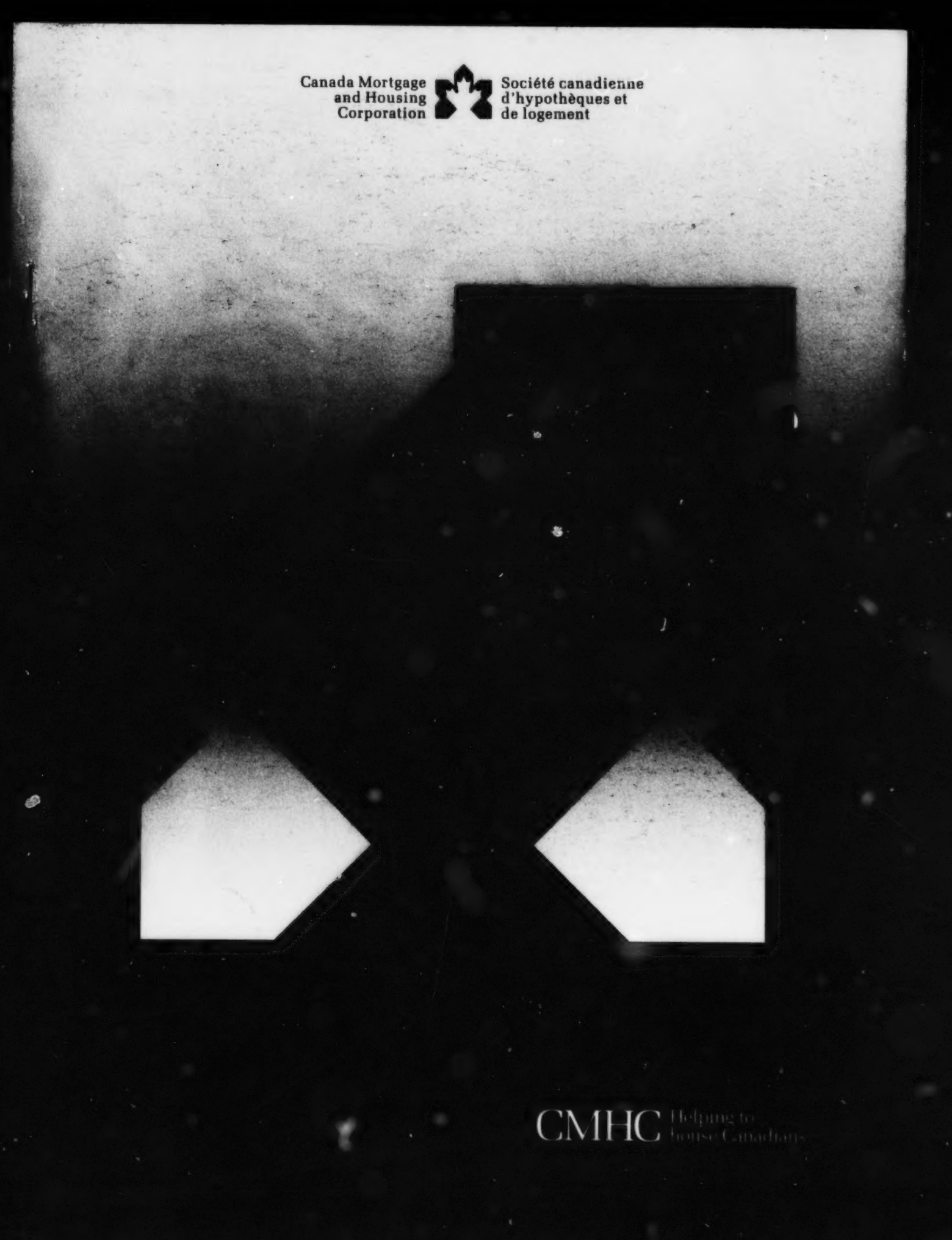

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LONG TERM LOADING OF RESIDENTIAL FLOOR TRUSSES

Submitted:

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1. INTRODUCTION

This report has been prepared as part of the work undertaken by Morrison Hershfield Limited (MH) for Canada Mortgage and Housing Corporation (CMHC) under CR File No. 6710-9. This project was an extension of Supply and Services Canada contract 43SS.IP001-3-5610-9. The original project was summarized in MH Report No. 78307021, dated December 1985, entitled "Development of Methodology for the Analysis of Residential Floor Trusses and submitted to Mr. D.E.R. Anderson, Senior Materials Evaluation Engineer, Canada Mortgage and Housing Corporation. CMHC's delegate for the management of the current project is Mr. Fred Plimmer.

The project was supported by donations of materials from the following companies:

- Gang-Nail Canada Ltd., Markham, Ontario
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2. BACKGROUND AND EXPERIMENTAL DESIGN

In the original project, eighty full size, wood, parallel chord residential floor trusses were tested to failure. Sixteen different truss configurations were tested and models were developed to predict the strength and stiffness of full size trusses based on tests of truss components. Figure 1 is taken from the original report and illustrates the truss configurations and the test results. Three basic types of floor trusses were tested. These were:

- trusses with metal webs (MW)
- trusses which used metal diagonal tension webs with wood vertical webs (TS) and
- trusses which used wooden webs (WW)

One of the major factors affecting the serviceability of floor trusses is their performance over time. Wood is known to continuously deflect or "creep" over time and weaken when a significant load is applied over a long time. Tests were carried out in order to study these effects on residential floor trusses.

Six of the original truss designs were selected for long-term loading tests. The six that were chosen were the following:

- MW-B
- MW-C
- TS-A
- TS-D
- WW-B
- WW-D

These trusses were chosen according to the following criteria:

(a) The spans were all of the same order, ie. roughly 4900 mm.
(b) Two different depths of each design type were to be used.
(c) A variety of end conditions were to be represented in the tests.

The number of replications was two, i.e. each design was represented by a pair of trusses which were loaded under long term loads together. Therefore, the total number of trusses tested was twelve.

A major decision which had to be made was the level of load to be applied to the trusses during the long-term tests. On the one hand, a fairly significant level of load was required so that some time-related behaviour would be detected; on the other hand, putting on the full design load for that period of time would be unrealistic. It was therefore decided to use a constant loading level throughout the period of the test equal to the dead load plus 1/2 of the live load.

The following are the loads applied:

- 1/2 live load = 0.96kN/m^2 (20 psf)
- top chord superimposed dead load = 0.5kN/m^2 (10 psf)
- bottom chord superimposed dead load = 0.2kN/m^2 (5 psf)
- total = 1.7kN/m^2 (35 psf)

For a tributary width of 610 mm (2 ft.) the total superimposed load on a pair of trusses is 2.0 kN/m (140 plf).

The above load level was used on five of the six trusses. The one exception was design WW-B; a wooden web truss with a depth of 298 mm. For this latter truss, the top chord dead load was taken at 0.2 kN/m^2 (5psf) leading to a total loading of 1.4 kN/m^2 (30 psf) and to a load for a pair of trusses of 1.7 kN/m (120 plf).

The long-term loads were sustained for a total of twenty-six months beginning November 29, 1983 and ending February 6, 1986. The loads were then removed and the trusses were tested to failure approximately one week later.

3. MATERIALS

Details of each of the truss designs are in the upper portions of Figures 2 to 7. The top and bottom chords consisted of 38 x 89 mm No. 2 and better spruce-pine-fir lumber used on the flat.

The flatwise flexural modulus of elasticity was measured for each piece of lumber to be used in the chords.

The trusses were manufactured in commercial fabricating shops according to standard manufacturing practice. Throughout the fabrication and handling processes, MH requested that no special treatment be given to the test trusses; they were to be made and handled by the manufacturer's standard or routine procedures. In the opinion of MH, the fabrication and handling of test trusses were generally in accordance with the truss design and with standard industry practice.

4. PREPARATION OF TESTING EQUIPMENT FOR FINAL LOADING

The floor truss tests were carried out by MH personnel at their Mississauga laboratory. The testing frame provided a free moving suspended support at one end of the truss and a fixed support for the other end. All trusses were supported at the bottom chord level.

All loads were applied to the top chord using a system of pneumatic jacks. the jacks were placed at 610 mm intervals along the length of the truss and pressure was exerted onto the truss through load spreader bars spaced at approximately 305 mm intervals. The jacks were actuated by compressed air and the resulting support reaction at the free end was measure by a load cell. Deflection measurements were made at the centreline and quarter points. An LVDT was used at the centreline and precision potentiometers

were used at the quarter points. Support deflections were also measured using precision potentiometers. Loads and deflections were recorded by a computer data acquisition system which produced load deflection curves at the time of the test.

5. TEST PROCEDURE

Prior to the actual load testing of the trusses, certain observations and preparations were made.

The first step was the collection of detailed observations of truss geometry. In this step, accurate measurements of the following were made and recorded:

- overall truss dimensions
- panel point locations
- plate and web sizes and locations
- gap widths between members and webs at the connections.

In addition, each truss was examined for unusual defects such as long splits, large knots or webs misaligned during the fabrication process.

A special mezzanine floor was built in the MH Research and Development Laboratory in Mississauga. The two trusses of each design type were set up together with plywood sheathing across their top chords, and were supported on a span equal to their maximum design span; these spans were the same as those used in the short term tests. The two trusses of each pair were braced together at their ends to provide lateral stability.

Double string lines were stretched from one support to the other as a means of measuring deflection of the trusses and paint was sprayed on the joint

between the tops of the web members and the chords as an aid in detecting any slip between the two elements.

Masonry blocks on top of the plywood sheathing were used to apply the load to the top chords. Care was taken to ensure that there were gaps between adjacent masonry blocks in order to prevent any arching action from taking place between the blocks.

The deflections were read and recorded each day at the same time for the first 30 days under load; thereafter, deflections were measured periodically. At the time the deflection readings were taken, temperature and relative humidity was recorded.

After 800 days, the load was removed. Deflections were read and recorded during the unloading and for seven days thereafter. Following this period, the trusses were loaded to failure in the test frame.

The loading procedure was similar to the loading sequence used in the original project i.e.:

(a) The loads were increased at equal intervals to a value equal to twice the live load plus the dead load and maintained for a three hour period.

(b) The live loads were removed and the dead load was maintained for ten minutes.

(c) The load was then increased to failure.

The cause of the failure and the load level were recorded.

6. TEST RESULTS

Figures 2 through 7 give the comparable test results from the original experiment. These will be used later for comparison purposes.

Figures 8 through 13 give the mid-span deflection under the sustained loads. Average mid-span deflections are presented in Figure 14. The equilibrium moisture contents (EMC) of the wood members were estimated based on the temperature and relative humidity measurements taken at the same time as the deflection readings. These EMC values are plotted along with the average deflections in Figure 14.

Table 1 summarizes the long term deflection data. Maximum long term deflection was measured after 800 days of sustained load. Permanent set deflection measurements were taken one week after the loads had been removed.

As noted previously, the flatwise flexural modulus of elasticity was measured prior to the assembly of the trusses. These measurements are summarized in Table 2.

Load/deflection curves for the final loading of the trusses are presented in Figures 15 through 20. Deflection measurements were zeroed prior to the application of the final loads. Therefore, the deflections represented in these figures do not include any of the permanent set sustained after the long term loading. Table 3 summarizes the final loading test results of these trusses including:

- ultimate load
- deflection at design load and
- a description of the failure

7. DISCUSSION OF RESULTS

7.1 Long Term Deflections

A review of Figures 8 through 10 indicate that although there are some differences between individual trusses within a truss pair, the deflection trends are similar for each truss type as would be expected since the trusses were loaded in pairs. Figure 14 illustrates how changes in moisture content and seasons affect long term deflection. The most pronounced increase in deflection coincides with a sharp rise in the predicted EMC of the wood. This increase in EMC was associated with another experiment in the Mississauga laboratory which raised the humidity.

The incremental increases in truss creep are consistent with the results presented by Suddarth Percival and Comus[1]. Based on the information presented in their paper, it would be expected that the trusses which were loaded in this experiment would have continued to creep at discreet intervals yearly.

The average maximum deflections and permanent set for each truss type were compared to the average design load deflections from the original tests. These comparisons are illustrated in Figure 21. An analysis of covariance forcing the relationship through the origin indicates that there are very predictable relationships between the maximum deflection and permanent set when compared to short term deflections. After twenty-six months of sustaining half live load plus dead load, truss deflection was approximately one and a half times the short term design load deflection. Assuming that the initial trusses were elastic to design load, the maximum long term

deflections were approximately 140 percent greater than the short term deflections.

7.2 Final Loading of Trusses

The final loading of the trusses will be discussed in terms of deflection at the design load, load capacity and failure modes.

Deflections at design load are given in Table 3. The average values were compared to the initial design load deflections of the original tests and the relationship is illustrated in Figure 21. A regression analysis indicated that the trusses which had sustained a long term load were approximately 28 percent stiffer when compared to the original tests. This apparent increase in stiffness can be attributed to the preloading of the trusses. Initially, there is a "settling in" of the trusses whereby the slack in the members and connections leads to an increase in deflections. Upon subsequent loadings, the truss will appear to be stiffer. This is consistent with the original tests where after the twice live load plus dead load had been maintained, the live loads were removed then reapplied. Upon reapplication of the loads, the average apparent increases in truss stiffness were as follows:

- MWB, 16%
- MWC, 28%
- TSA, 43%
- TSD, 41%
- WWB, 12% and
- WWD, 16%

Overall there was a very good correlation between stiffness of the original trusses and stiffness of these trusses.

In this study, there were no significant differences between the failure loads after sustaining a long term load and the initial tests. This relationship is clearly shown in Figure 22.

Except for the MWB trusses, all of the failure modes were consistent with failure modes seen in the original tests. Failure in Truss MWB-South was initiated at joint 13. At this location, the web plate was visibly overpressed and the wood had split. This obviously weak location, led to failure. A spike knot at joint 13 may have contributed to the failure of Truss MWB-North. There is no conclusive reason why the failure mode of this truss would be different from previous trusses.

8. SUMMARY AND CONCLUSIONS

1) After holding dead load plus half live load for 26 months, residential floor trusses sustained deflection approximately 1.5 times greater than initial deflections at design load. Deflections increased incrementally with changes in interior temperatures and relative humidity.

2) Permanent set one week after the loads were removed were approximately equal to the initial deflection at design load.

3) Trusses were approximately 28 percent stiffer than the comparable trusses originally tested. This increase in stiffness can be attributed to the "settling in" effect.

4) The long term loading in this project had little affect on failure loads or modes of failure.

5) The models presented in the original report can readily be modified to account for the long term loading effects noted above. As noted in Section 2, the long term load levels were chosen to match other studies. Future projects to determine actual long term loads on residential floors would aid in the design of floor trusses.

(1) Suddarth, S.K., D.H. Percival and Q.B. Comus, 1981. Testing and analysis of 4 x 2 parallel-chord metal-plate-connected trusses. Research Report 81-1, Small Homes Council-Building Research Council, University of Illinois at Urbana Champaign

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TABLE 1

SUMMARY OF LONG TERM DEFLECTIONS

Truss	Maximum Long-Term Deflection (mm/mm length)	Permanent Set (mm/mm length)
MWB-South	0.0062	0.0040
MWB-North	0.0053	0.0029
MWC-South	0.0032	0.0017
MWC-North	0.0037	0.0024
TSA-South	0.0063	0.0043
TSA-North	0.0053	0.0032
TSD-South	0.0030	0.0020
TSD-North	0.0030	0.0018
WWB-South	0.0044	0.0029
WWB-North	0.0036	0.0021
WWD-South	0.0036	0.0021
WWD-North	0.0030	0.0017

TABLE 2

FLATWISE FLEXURAL MODULUS OF ELASTICITY OF THE TRUSS CHORDS

Truss	Modulus of Elasticity (MPa)			
	Top Chord		Bottom Chord	
	Long Member	Short Member	Long Member	Short Member
MWB-South	8,400	-	9,400	-
MWB-North	9,400	-	9,500	-
MWC-South	9,500	-	10,200	-
MWC-North	10,000	-	8,600	-
TSA-South	9,600	10,500	10,000	15,500
TSA-North	11,100	10,600	8,600	8,800
TSD-South	10,600	12,200	12,200	10,700
TSD-North	11,400	11,200	13,000	12,200
WWB-South	8,700	-	10,600	-
WWB-North	10,600	-	10,100	-
WWD-South	8,800	9,300	13,600	8,900
WWD-North	9,500	11,800	11,800	8,900

TABLE 3

SUMMARY OF LONG-TERM TEST RESULTS

Truss	Ultimate Load (kN/m)	Deflection at Design Load (mm/mm/length)	Type of Failure*
MWB-South	3.55	0.0031	Bottom chord tension failure between 12 and 13 initiated at joint 13.
MWB-North	3.42	0.0029	Outside web tooth/wood push out in compression at 13.
MWC-South	2.78	0.0015	Compression web tooth pullout at 12.
MWC-North	3.41	0.0016	Compression web buckling and tooth pullout at 12.
TSA-South	4.43	0.0030	Bottom chord splice tooth withdrawal.
TSA-North	4.82	0.0029	Bottom chord splice tooth withdrawal.
TSD-South	5.12	0.0016	Bottom chord splice tooth withdrawal.
TSD-North	6.04	0.0015	Tooth withdrawal from bottom chord at 5.
WWB-South	4.44	0.0021	Tension web tooth withdrawal at 11.
WWB-North	5.55	0.0019	Tension web tooth withdrawal at 11.
WWD-South	3.96	0.0019	Bottom chord splice plate in tension.
WWD-North	3.89	0.0018	Bottom chord splice plate in tension.

* for failure locations refer to Figures 2 through 7.

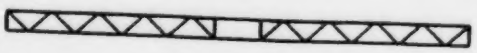
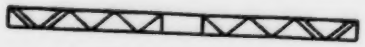
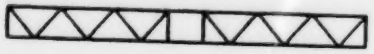
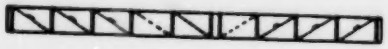
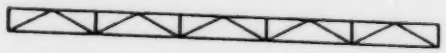
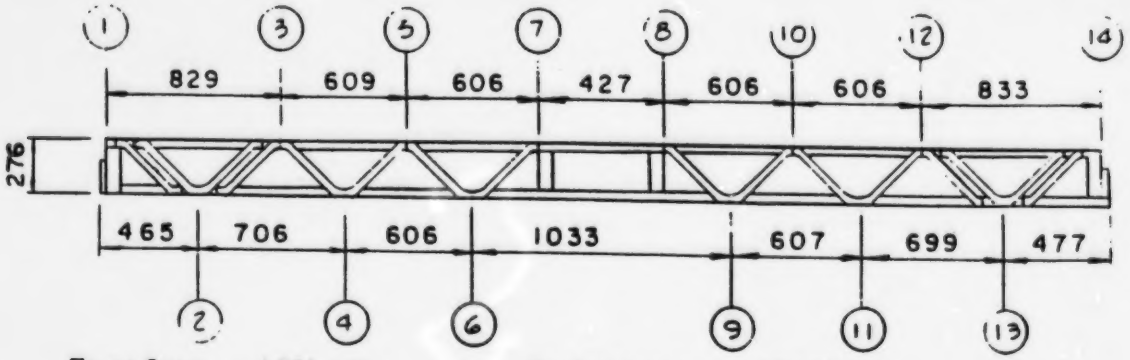
DESIGN	TRUSS DEPTH (mm)	SPAN (mm)	DESIGN LOADING (kN/m)	GENERAL TRUSS CONFIGURATION	DEFLECTION AT DESIGN LOAD	FAILURE LOAD / DESIGN LOAD
MW-A	276	6020	0.80		L/284	2.02
MW-A (MODIFIED)					L/354	3.31
MW-B	276	4521	1.60		L/283	2.25
MW-C	402	4648	1.60		L/465	2.04
MW-D	402	5461	1.60		L/303	1.89
MW-D (MODIFIED)					L/350	1.80
TS-A	320	4932	1.60		L/260	2.37
TS-A (MODIFIED)					L/308	2.63
TS-B	317	3182	1.28		L/636	3.55
TS-C	402	3877	1.60		L/554	3.19
TS-D	402	5002	1.60		L/455	2.99
TS-D (MODIFIED)					L/431	2.41
WW-A	298	5918	1.08		L/282	2.39
WW-B	299	4774	1.46		L/398	3.25
WW-C	397	6268	1.28		L/392	2.45
WW-D	397	5350	1.60		L/412	2.38

FIGURE 1 - AVERAGE ORIGINAL RESULTS FOR FULL-SIZE TRUSS TESTS



Truss Span = 4521 mm Design Load = 1.60 kN/m

Truss #	Ultimate Load (kN/m)	Deflection At Design Load (mm)	Type of Failure
MWB-1	3.62	17	Outside web tooth/wood pullout in tension at 14.
MWB-2	3.38	14	Wood tension failure at 1.
MWB-3	3.68	17	Wood tension failure at 1.
MWB-4	3.71	16	Outside web tooth pullout in tension at 14.
MWB-5	3.66	15	Outside web tooth/wood pullout in tension at 13.
Avg.	3.60	16	

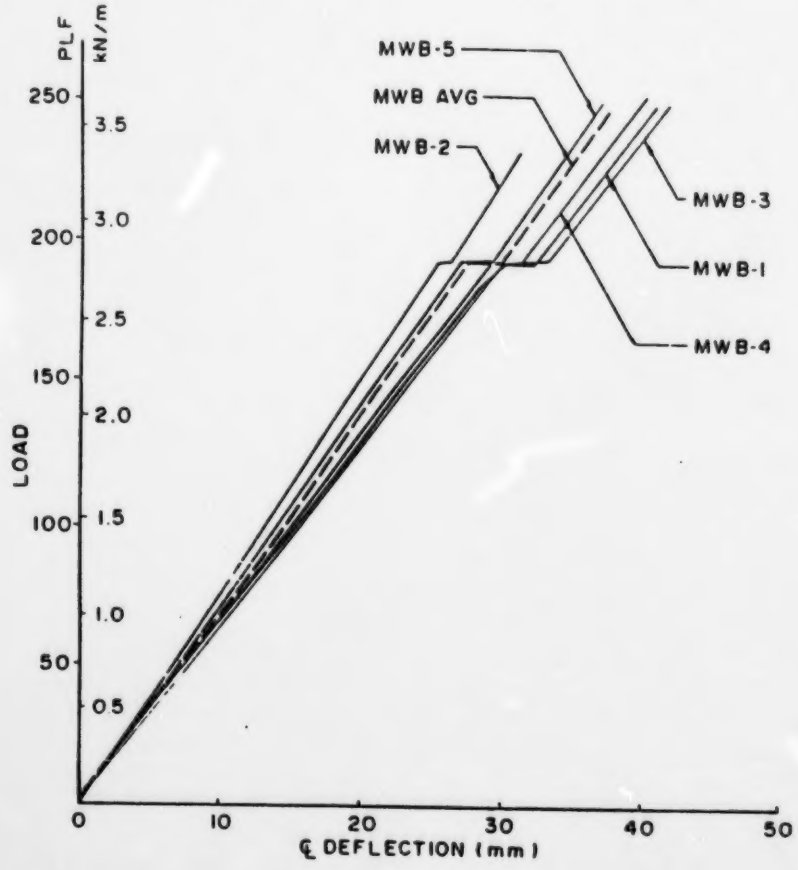
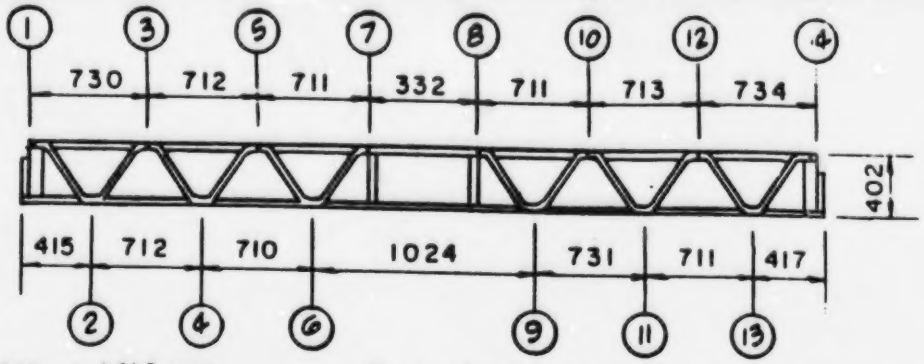


FIGURE 2 - MWB ORIGINAL TRUSSES



Truss Span = 4648 mm Design Load = 1.60 kN/m

Truss #	Ultimate Load (kN/m)	Deflection At Design Load (mm)	Type of Failure
MWC-1	3.88	11	Buckling of web 2-3
MWC-2	2.77	10	Web tooth/wood pullout in tension at 14.
MWC-3	3.65	10	Compression web buckling and tooth pullout at 12
MWC-4	3.27	8	Compression web buckling and tooth pullout at 12.
MWC-5	2.77	11	Web tooth pullout in tension at 12.
Avg.	3.27	10	

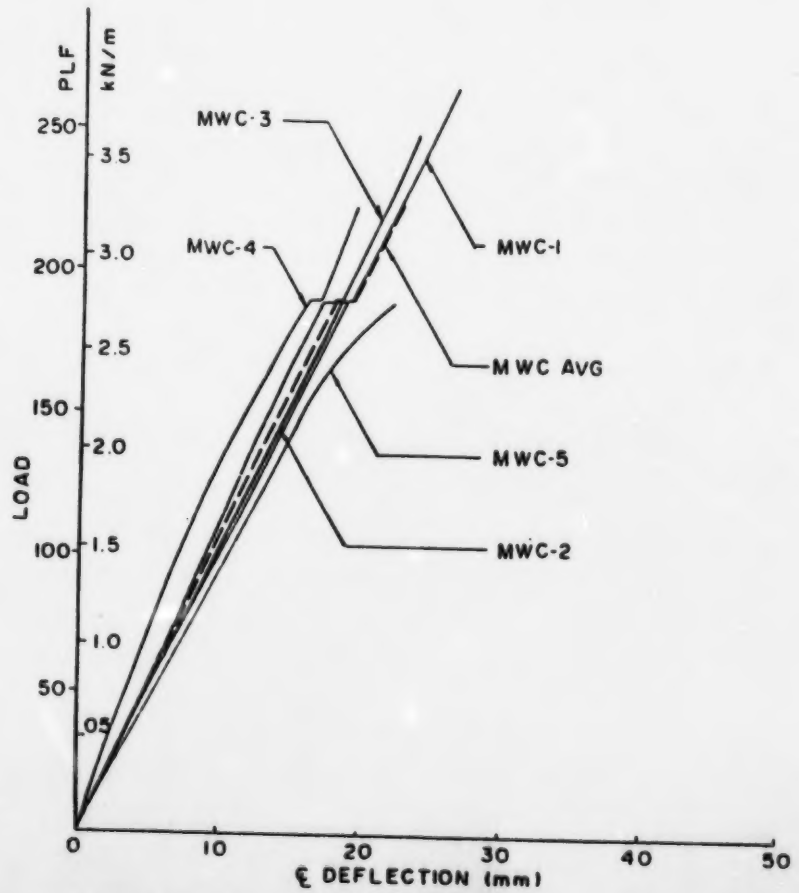
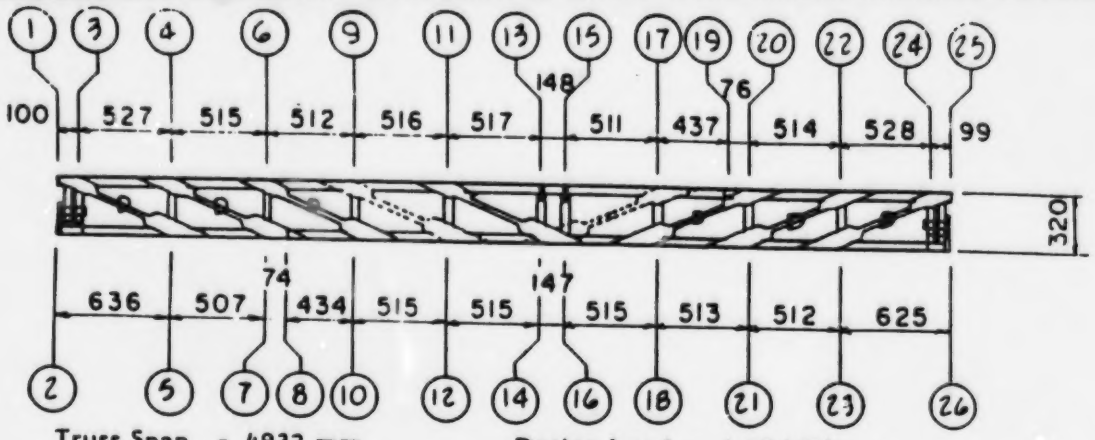


FIGURE 3 - MWC ORIGINAL TRUSSES



Truss Span = 4932 mm Design Load = 1.60 kN/m

Truss #	Ultimate Load (kN/m)	Deflection At Design Load (mm)	Type of Failure
TSA-1	3.60	19	Bottom chord splice tooth withdrawal.
TSA-2	4.17	19	Bottom chord splice tooth withdrawal.
TSA-3	4.17	18	Bottom chord splice tooth withdrawal.
TSA-4	3.31	20	Bottom chord splice tooth withdrawal.
TSA-5	3.79	19	Bottom chord splice tooth withdrawal.
Avg.	3.81	19	

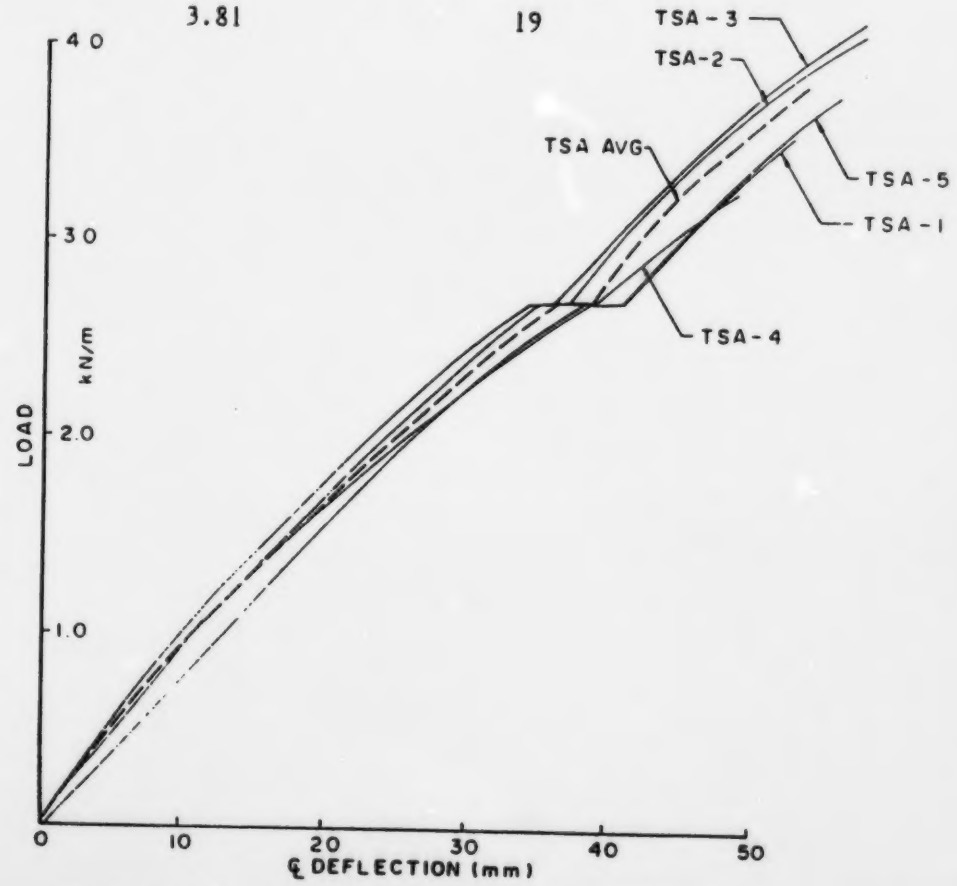
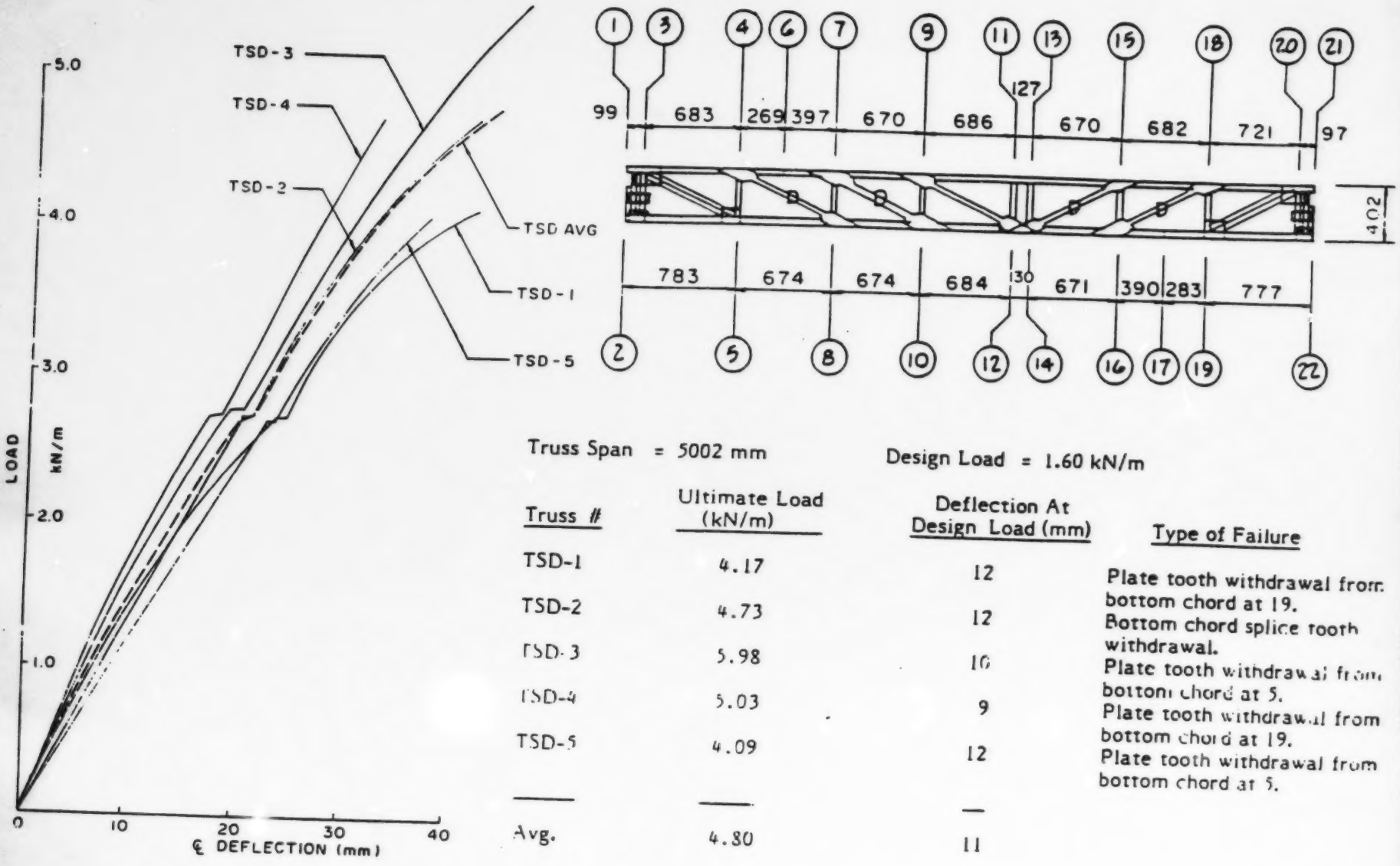


FIGURE 4 - TSA ORIGINAL TRUSSES

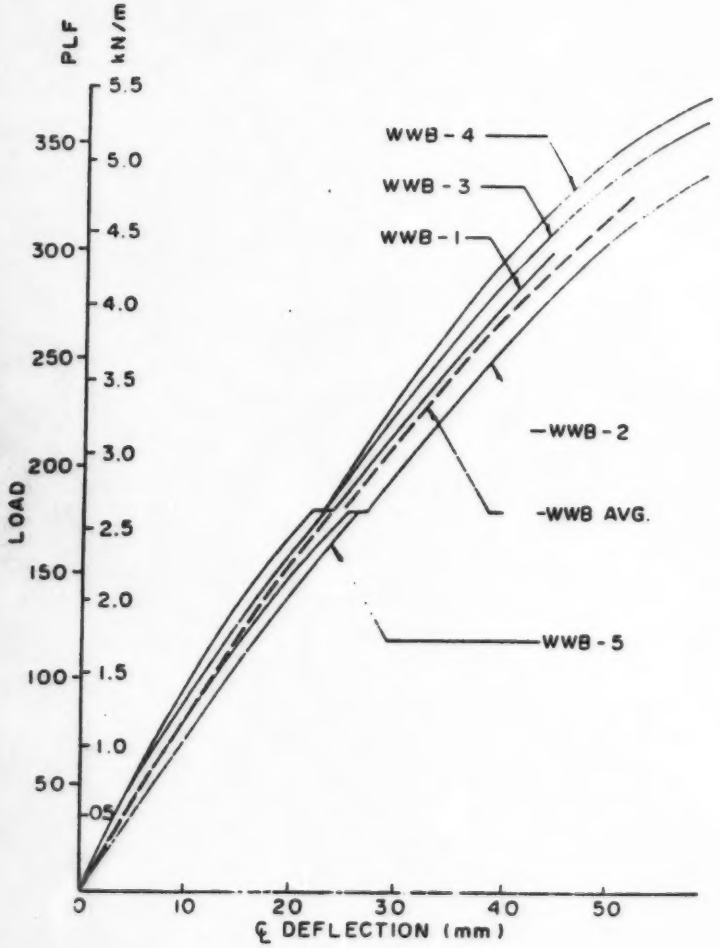


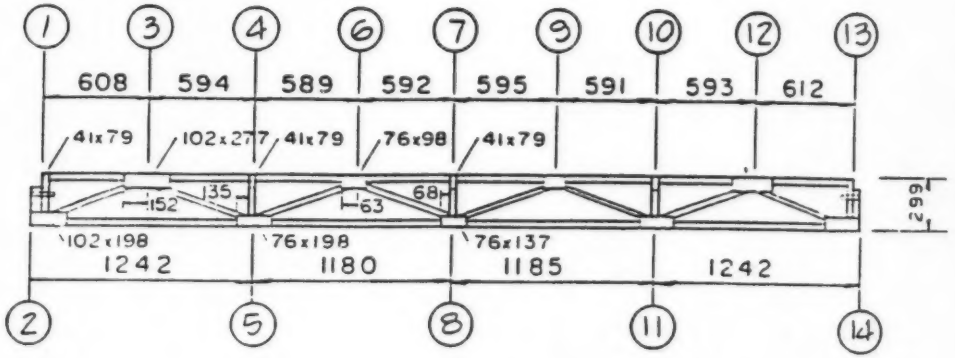
Truss Span = 5002 mm

Design Load = 1.60 kN/m

Truss #	Ultimate Load (kN/m)	Deflection At Design Load (mm)	Type of Failure
TSD-1	4.17	12	Plate tooth withdrawal from bottom chord at 19.
TSD-2	4.73	12	Bottom chord splice tooth withdrawal.
TSD-3	5.98	10	Plate tooth withdrawal from bottom chord at 5.
TSD-4	5.03	9	Plate tooth withdrawal from bottom chord at 19.
TSD-5	4.09	12	Plate tooth withdrawal from bottom chord at 5.
Avg.	4.80	11	

FIGURE 5 - TSD ORIGINAL TRUSSES



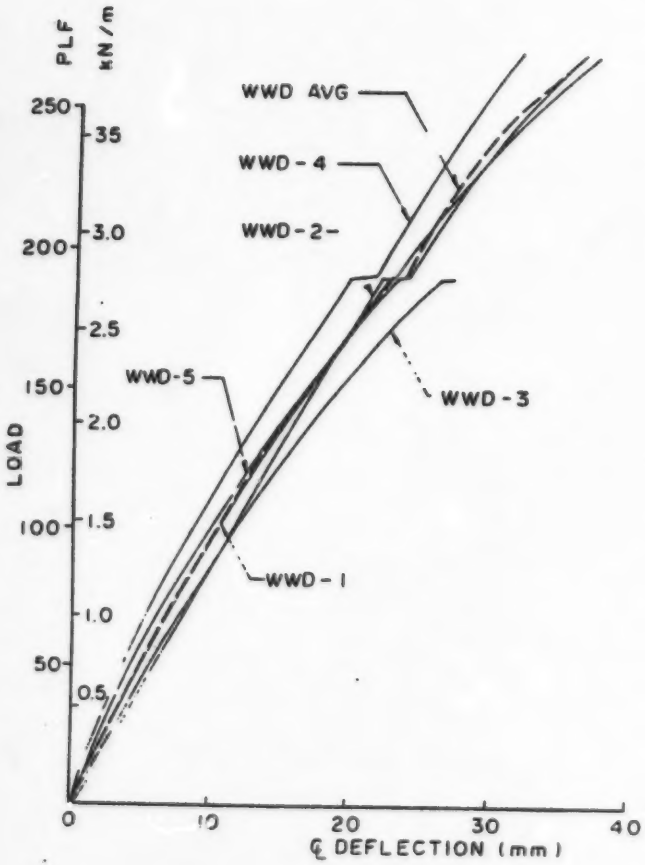


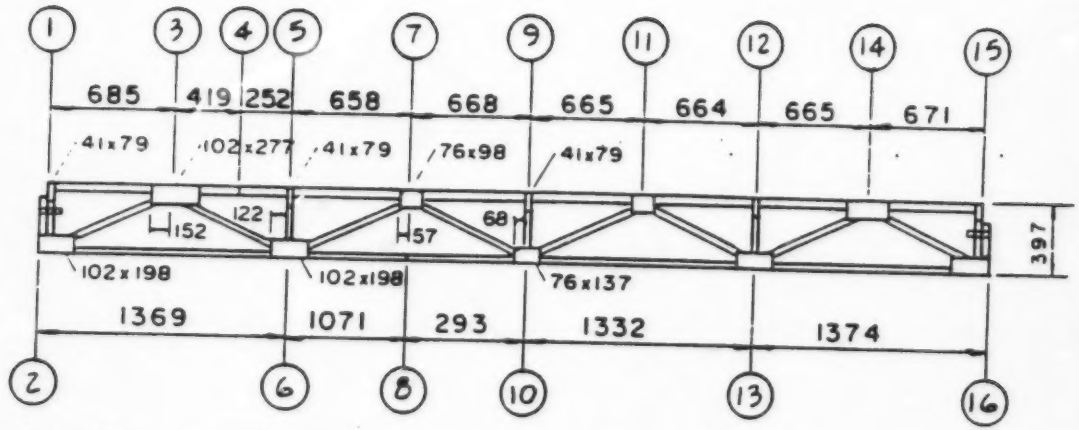
Truss Span = 4774 mm

Design Load = 1.46 kN/m

Truss #	Ultimate Load (kN/m)	Deflection At Design Load (mm)	Type of Failure
WWB-1	4.67	11	Bottom chord wood/ plate failure at 5.
WWB-2	5.25	13	Bottom chord wood/ plate failure at 11.
WWB-3	5.46	11	Bottom chord wood/ plate failure at 11.
WWB-4	5.69	12	Top chord bending between 9 & 10.
WWB-5	2.63.	14	Bottom chord bending between 3 & 11.
Avg.	4.74	12	

FIGURE 6 - WWB ORIGINAL TRUSSES





Truss Span = 5350 mm

Design Load = 1.60 kN/m

Truss #	Ultimate Load (kN/m)	Deflection At Design Load (mm)	Type of Failure
WWD-1	3.65	13	Bottom chord tension between 10 & 13.
WWD-2	4.10	13	Bottom chord splice in tension.
WWD-3	3.06	14	Bottom chord tension between 10 & 13
WWD-4	4.19	11	Bottom chord splice in tension.
WWD-5	4.09	12	Bottom chord splice in tension.
Avg.	3.82	13	

FIGURE 7 - WWD ORIGINAL TRUSSES

MWB LONG TERM LOADING

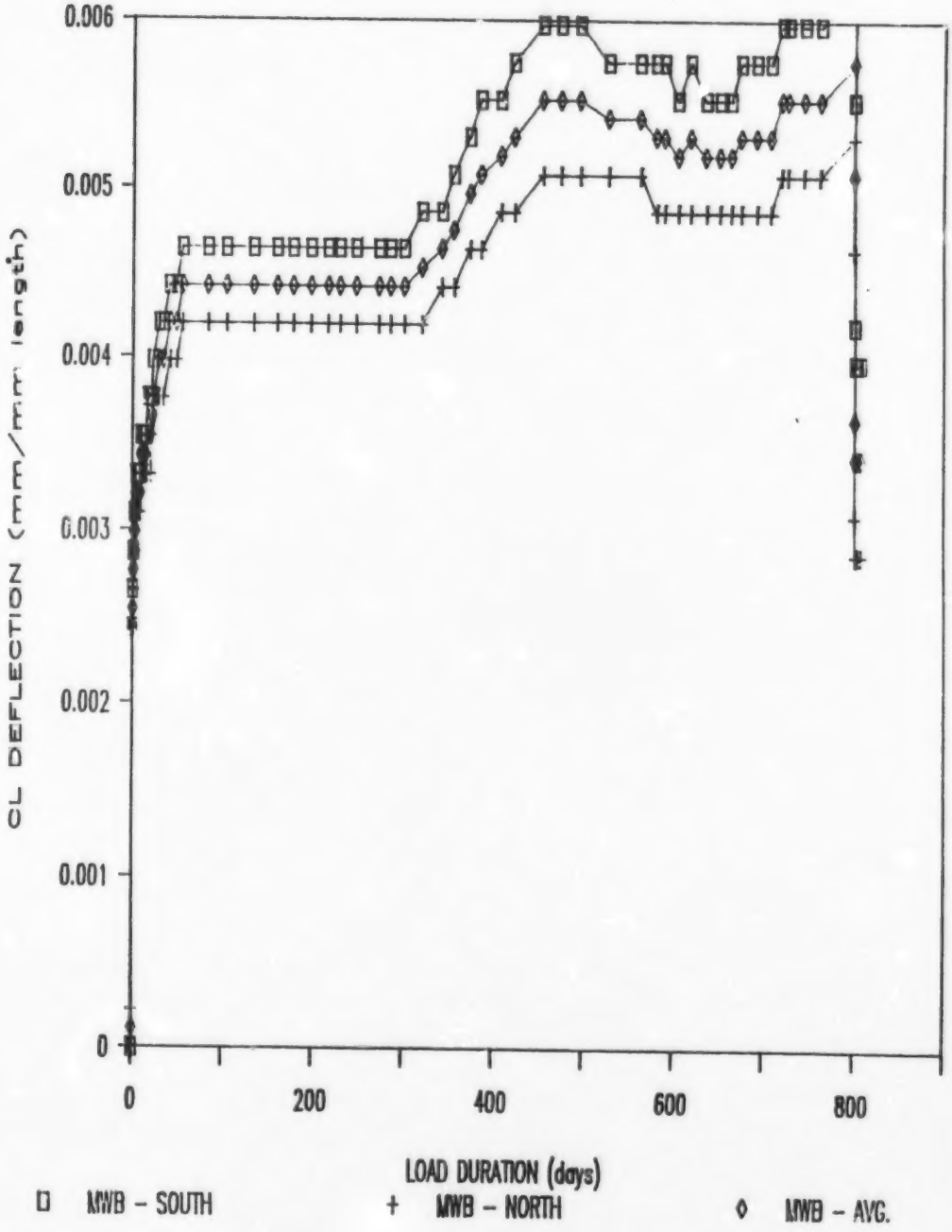


FIGURE 8

MWC LONG TERM LOADING

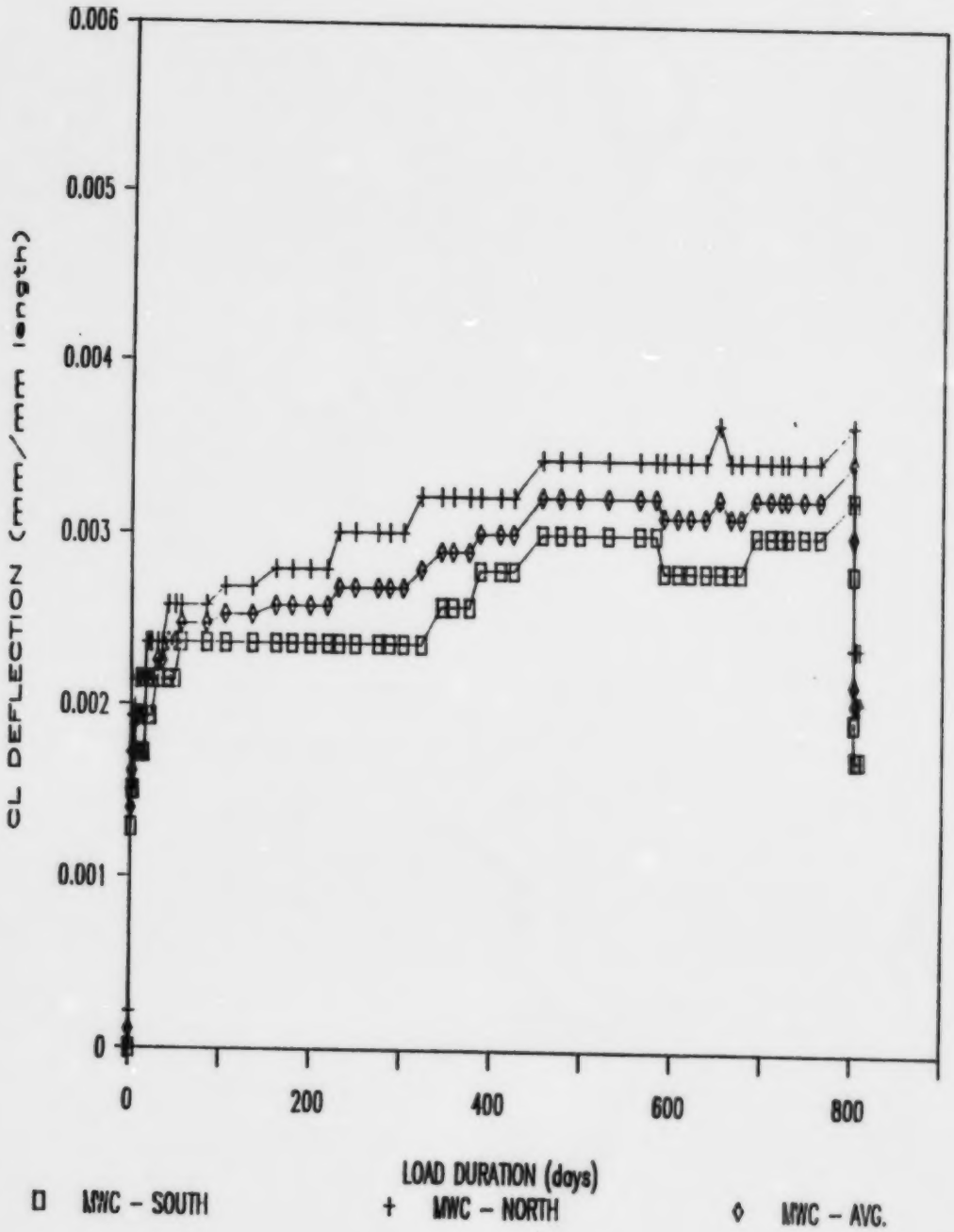


FIGURE 9

TSA LONG TERM LOADING

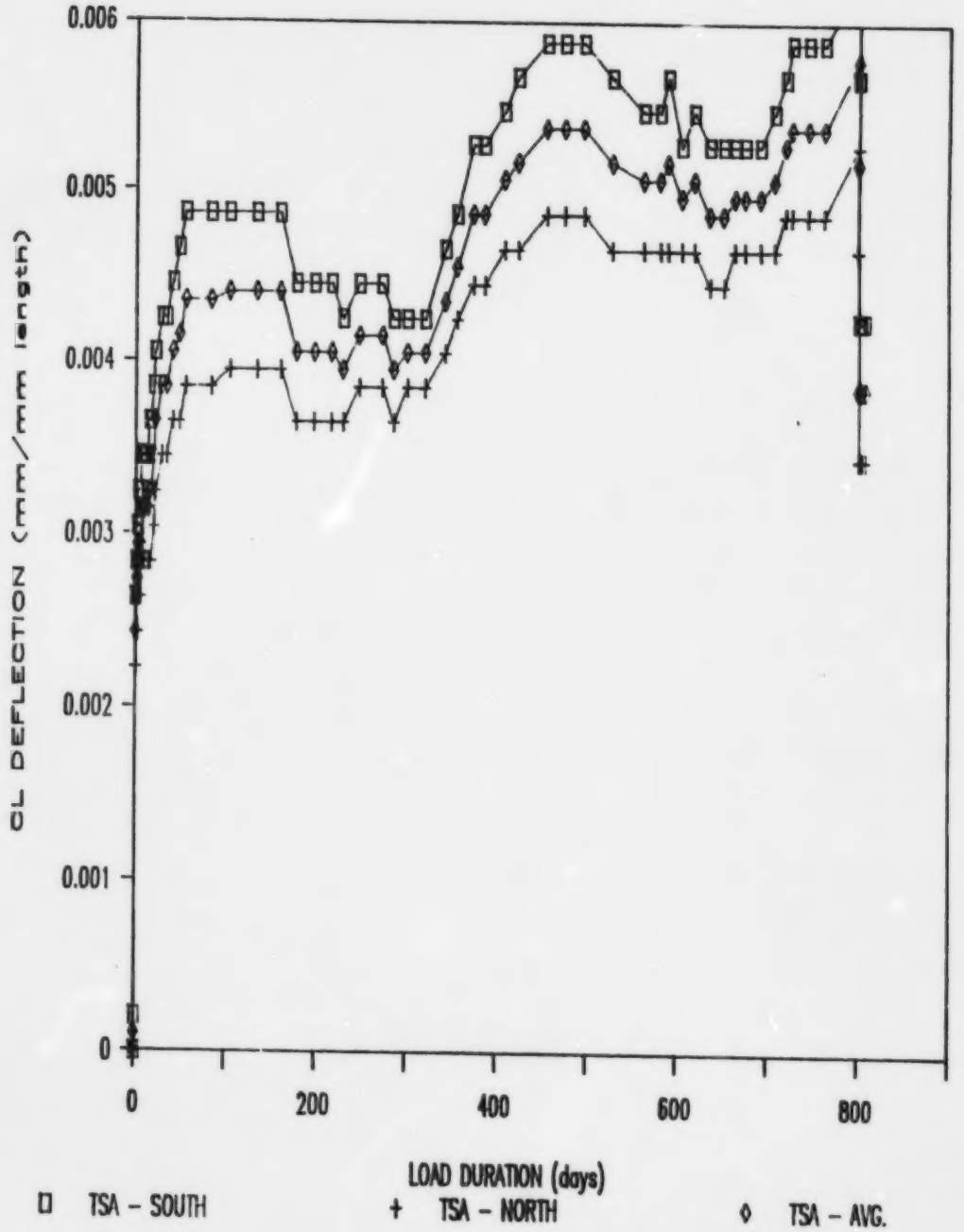


FIGURE 10

TSD LONG TERM LOADING

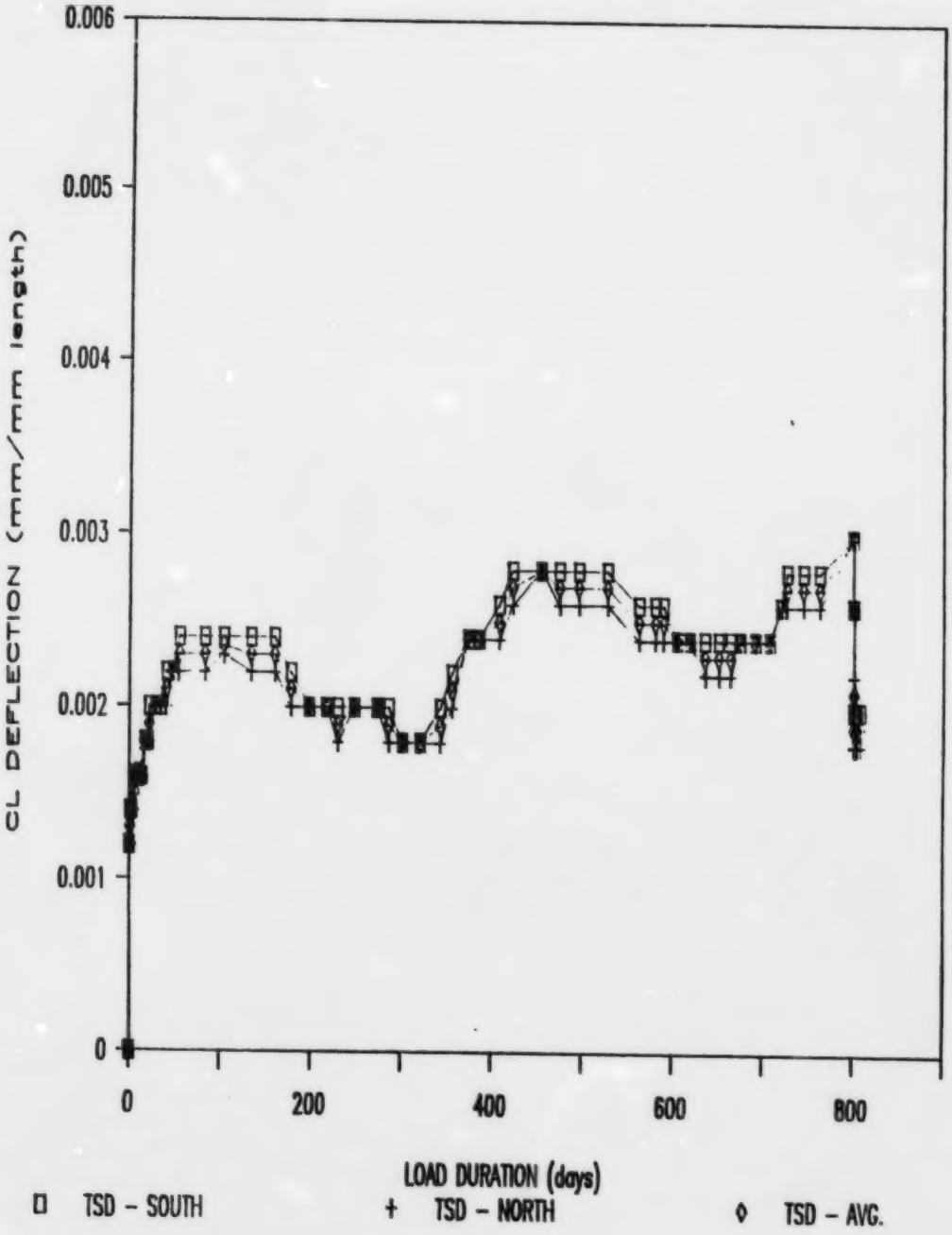


FIGURE 11

WWB LONG TERM LOADING

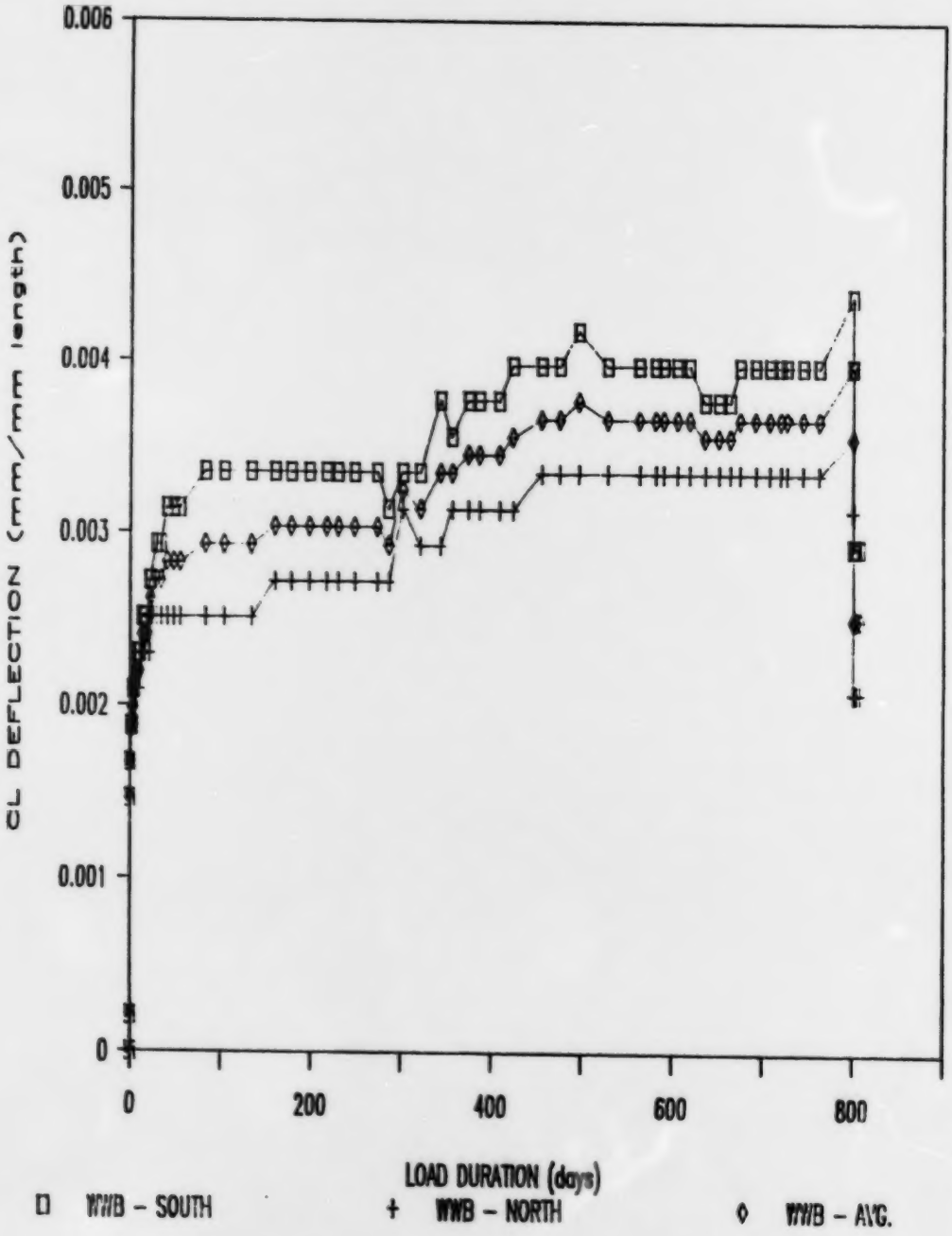


FIGURE 12

WWD LONG TERM LOADING

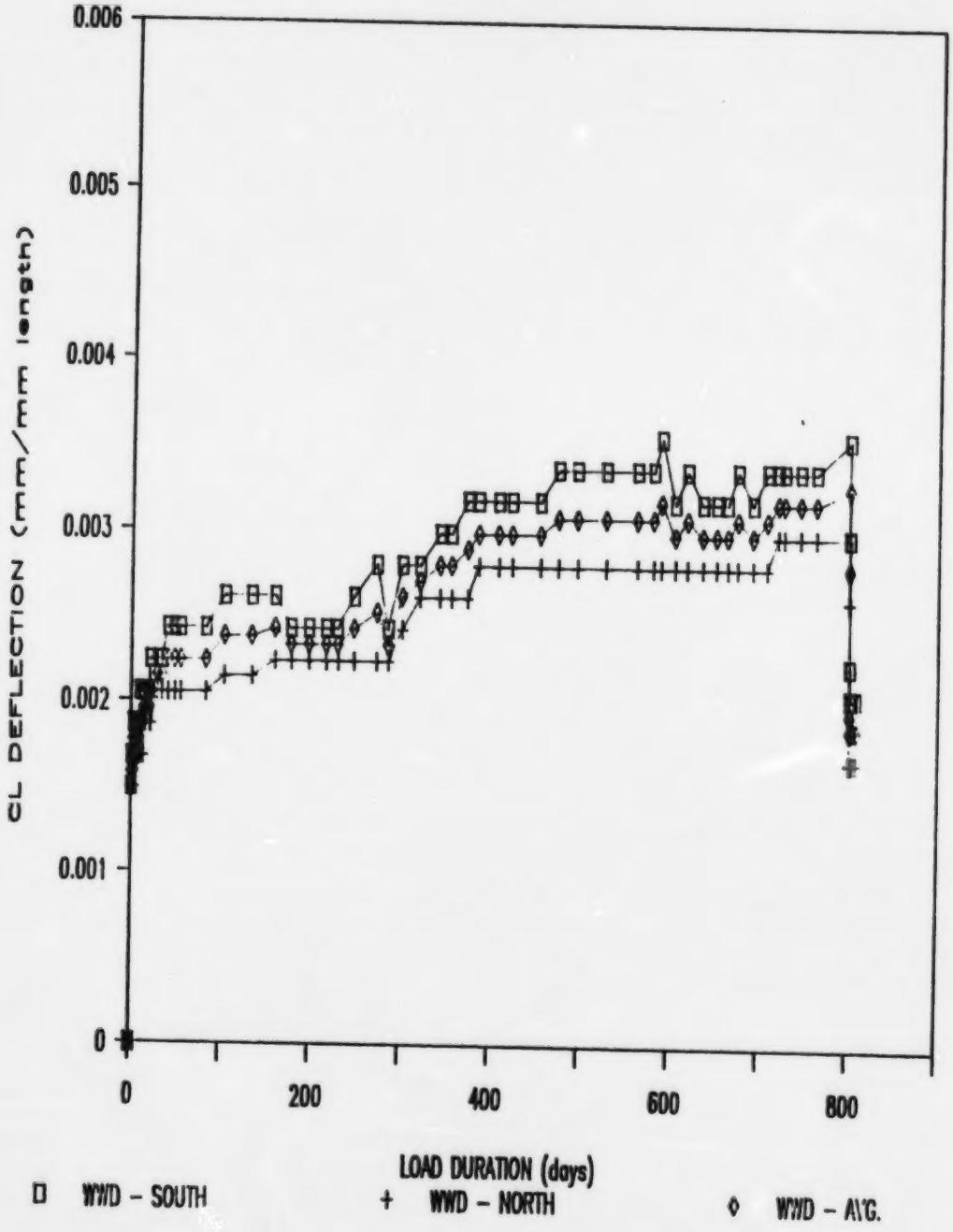


FIGURE 13

AVERAGE LONG TERM DEFLECTIONS

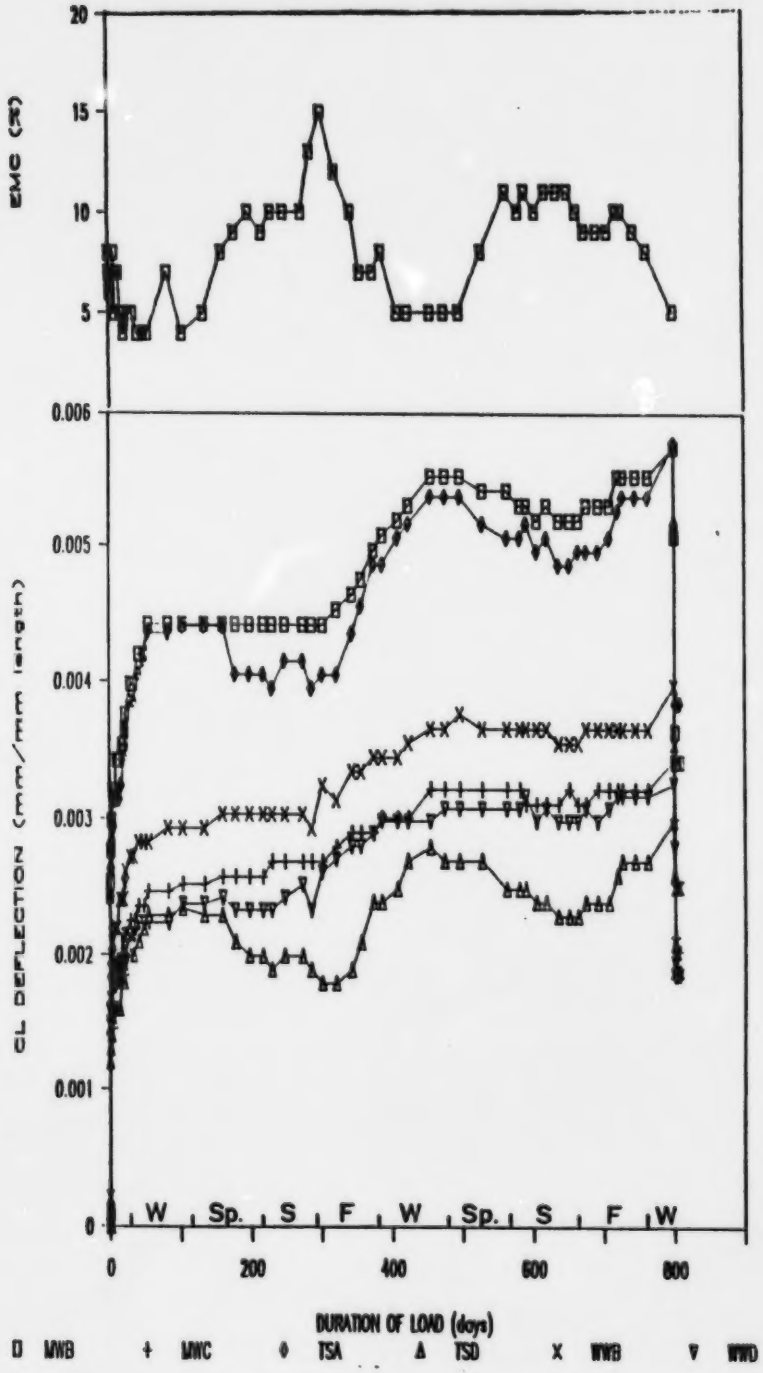


FIGURE 14

MWB FINAL LOADING OF TRUSSES

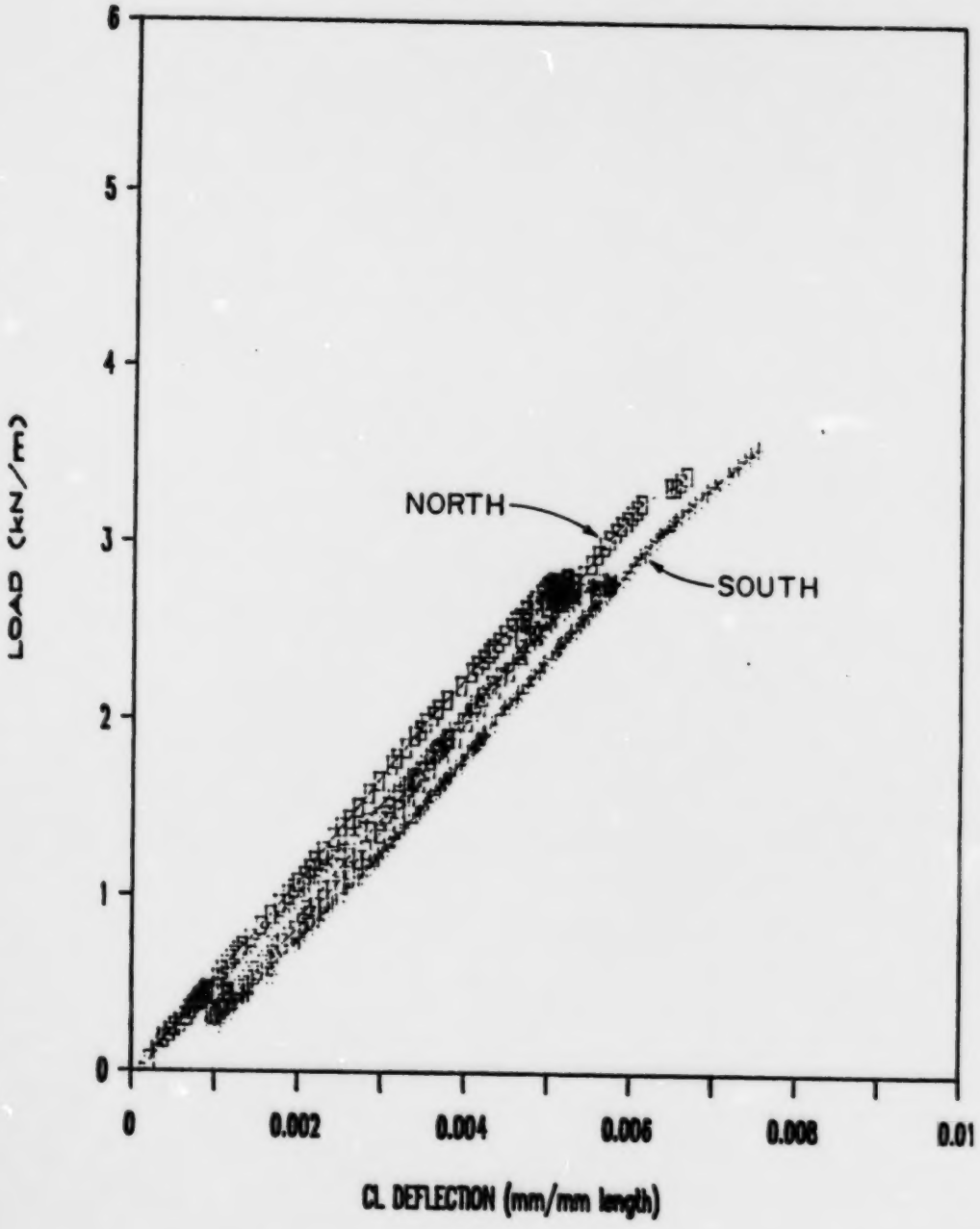


FIGURE 15

MWC FINAL LOADING OF TRUSSES

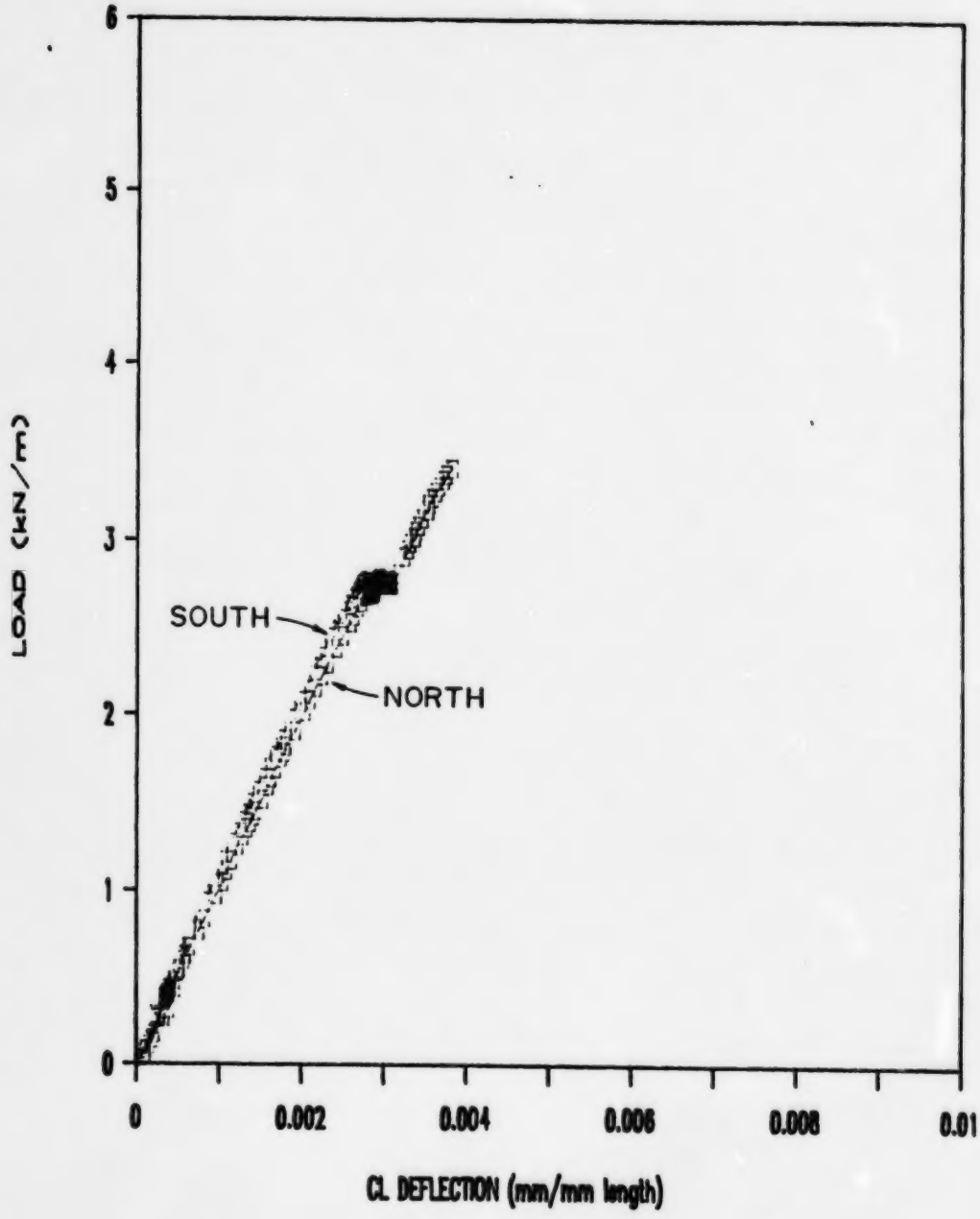


FIGURE 16

TSA FINAL LOADING OF TRUSSES

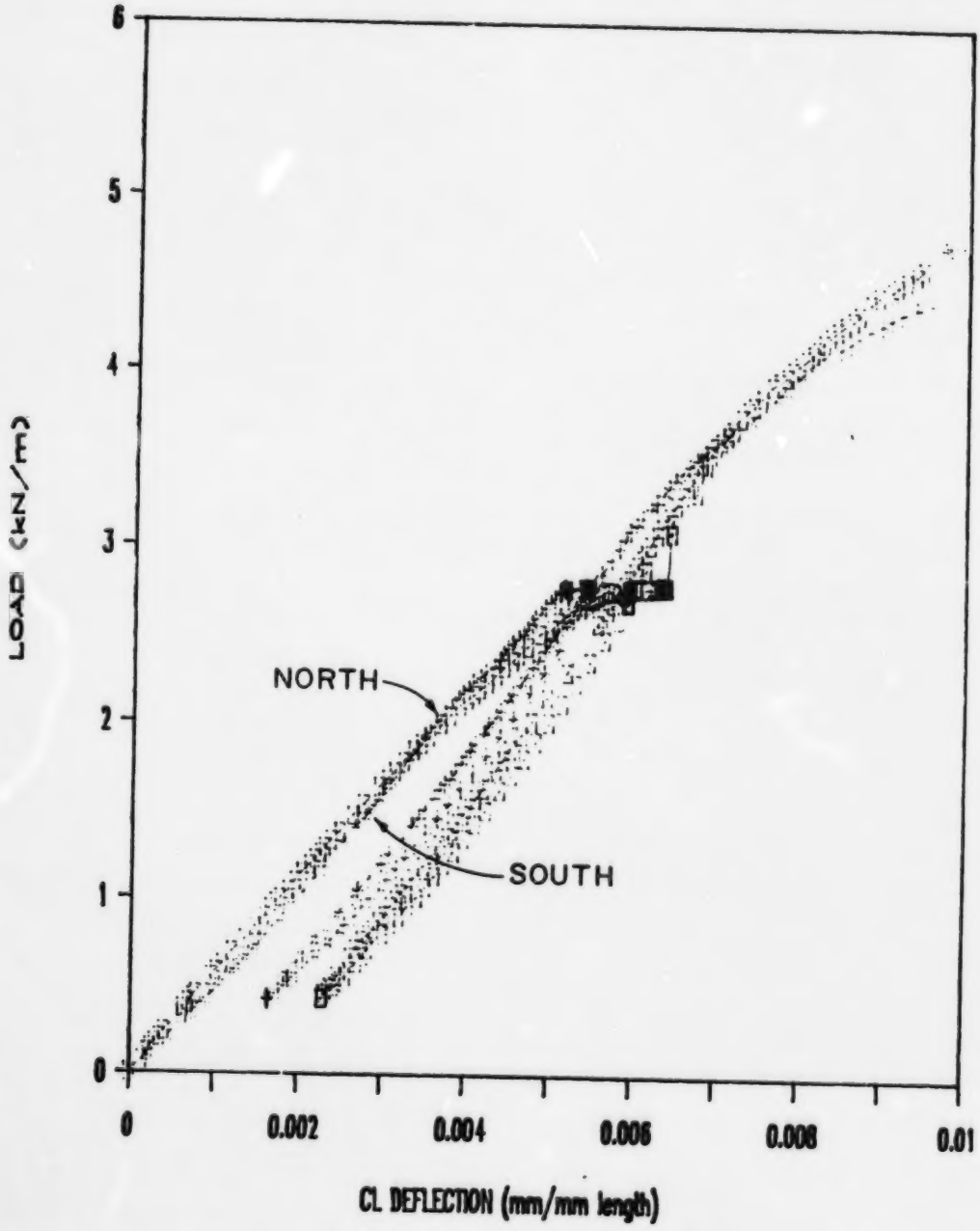


FIGURE 17

TSD FINAL LOADING OF TRUSSES

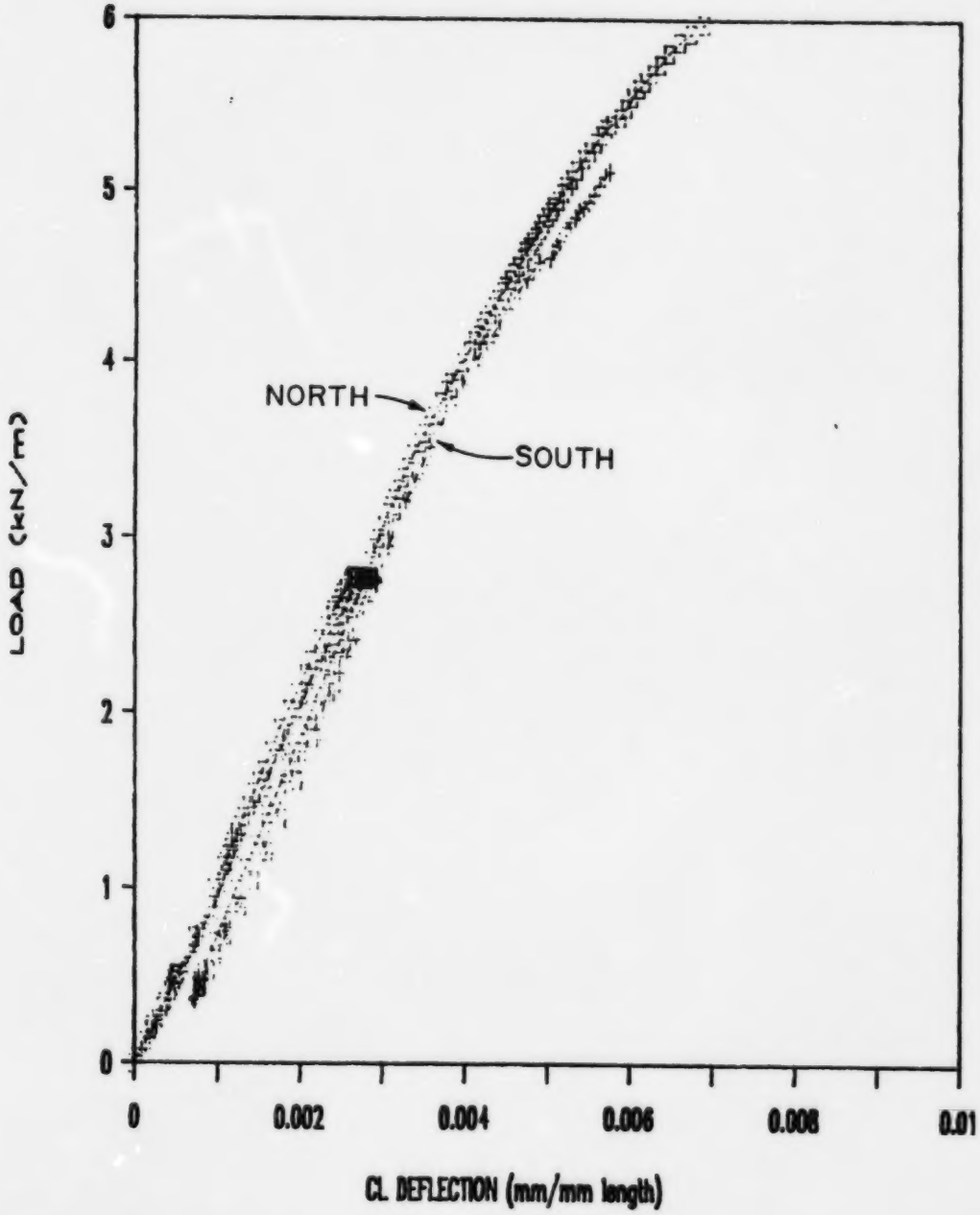


FIGURE 18

WWB FINAL LOADING OF TRUSSES

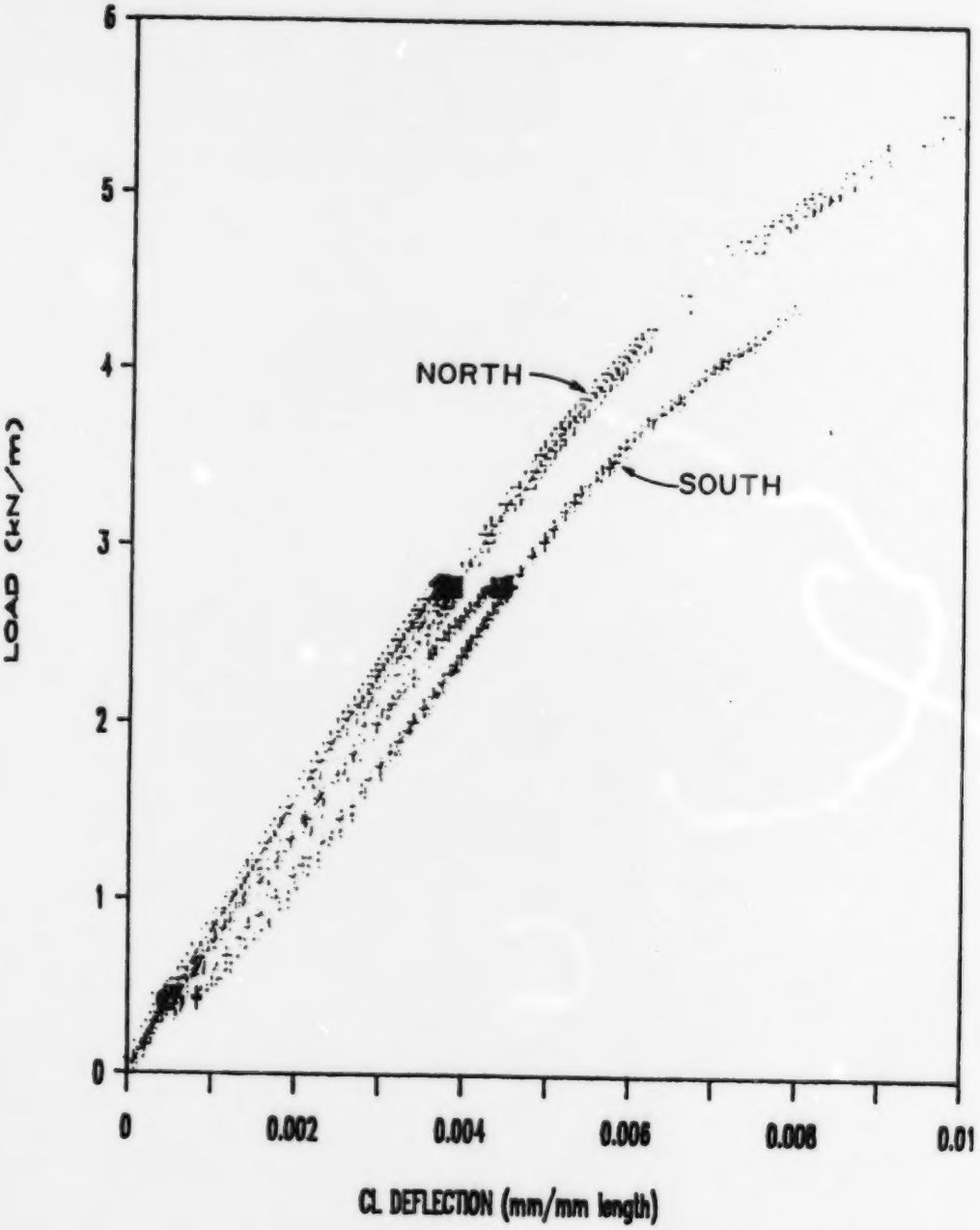


FIGURE 19

WWD FINAL LOADING OF TRUSSES

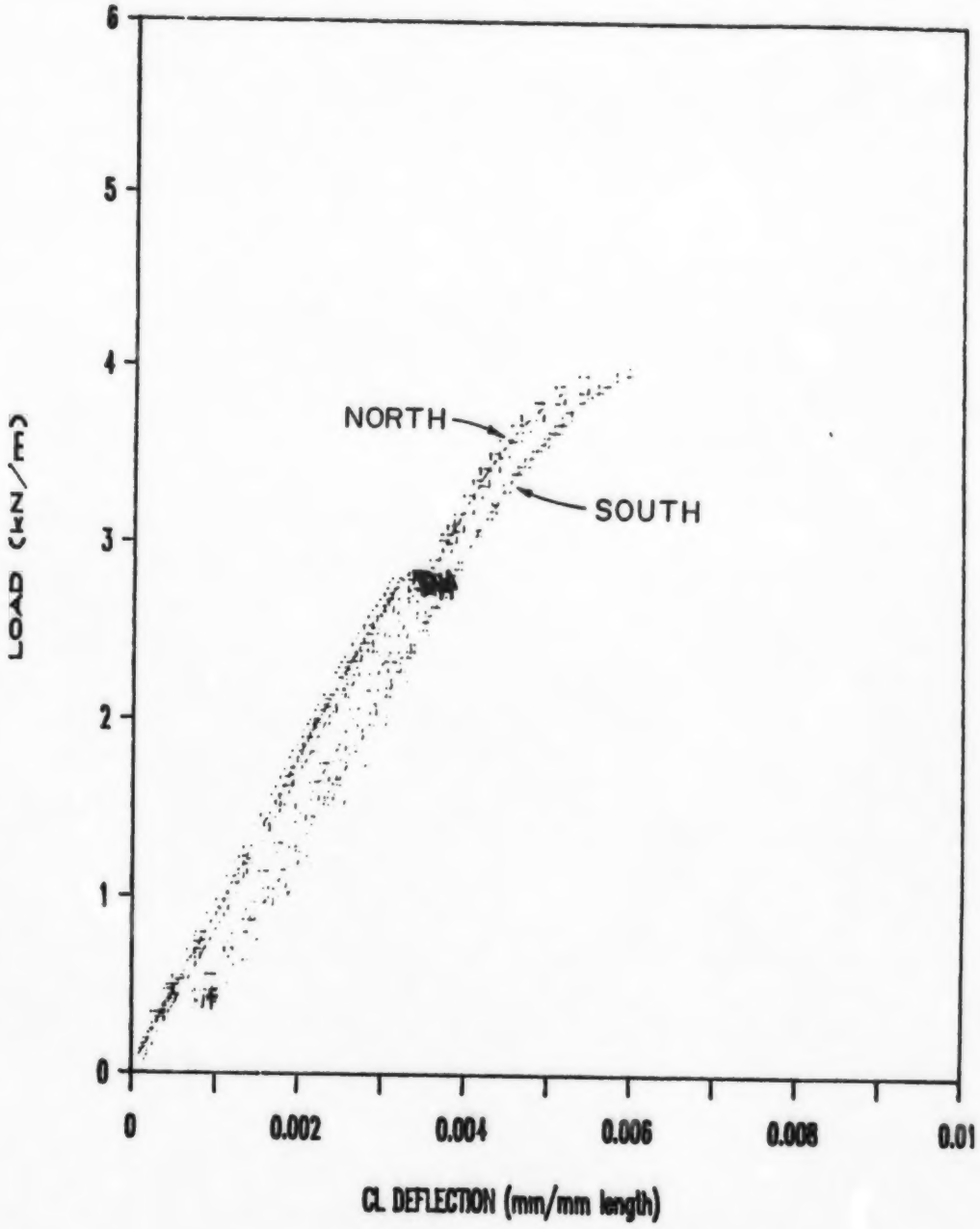


FIGURE 20

DEFLECTION COMPARISONS

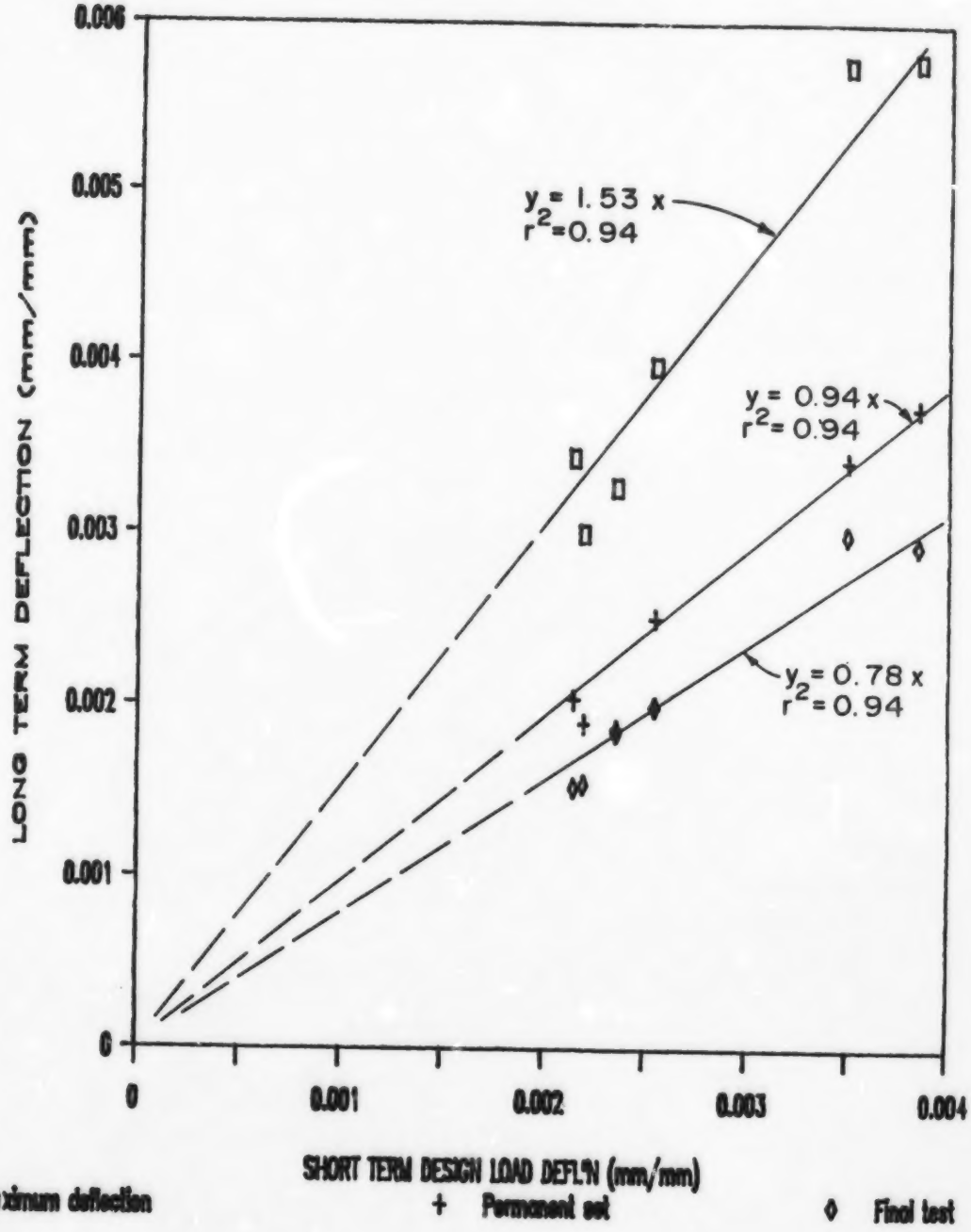


FIGURE 21

STRENGTH COMPARISONS

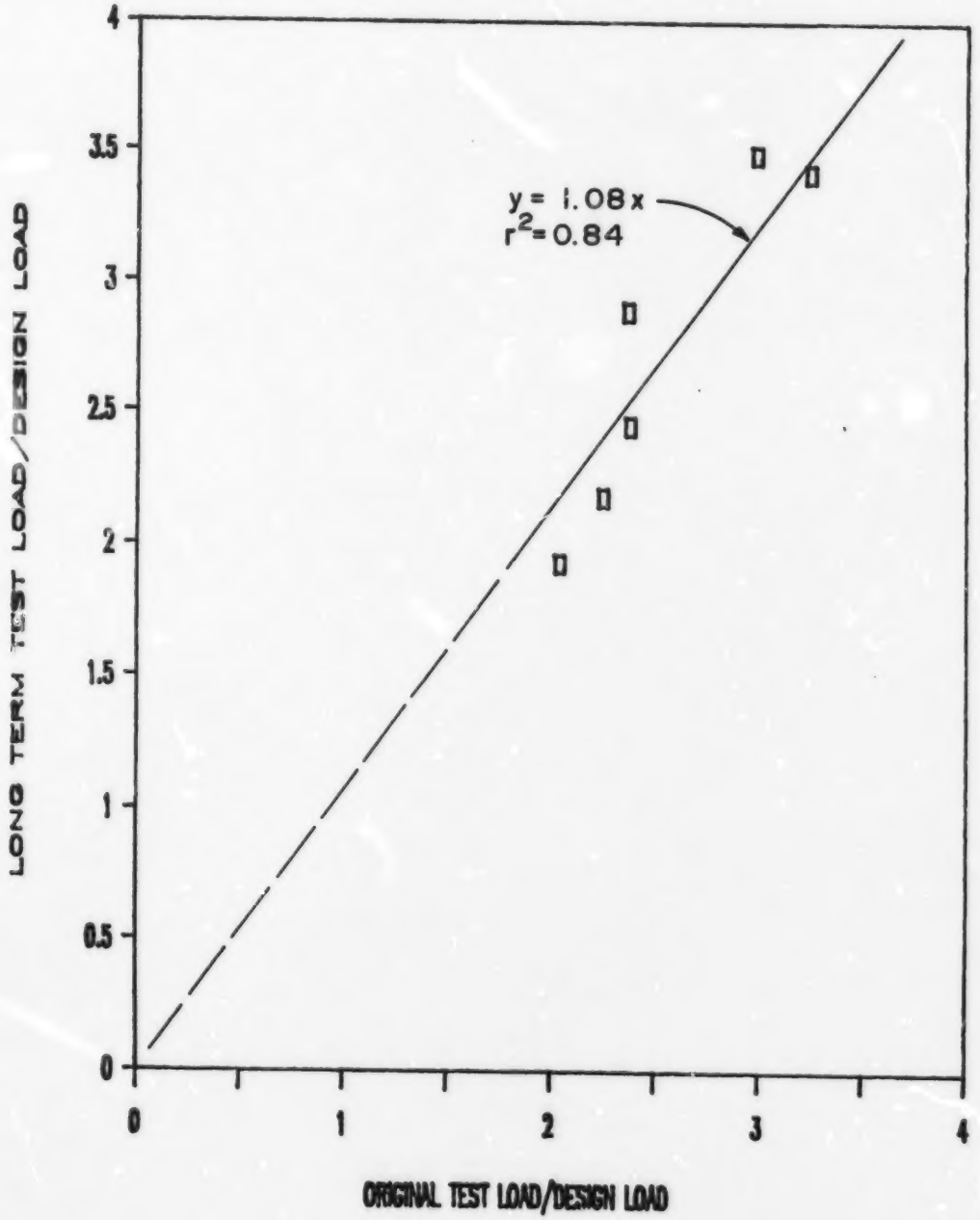


FIGURE 22